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Streamflow and Salt Flux in Seasonal Rivers: The Case of the Semi-Arid Tiva River Basin, Kenya

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Abstract

This paper presents the results of a study on the influence of streamflow variability on salinity, total dissolved solids (TDS) and conductivity in a semi-arid Tiva River Basin in Kenya. Measurements of salinity, TDS, conductivity and river discharges were undertaken in sampling stations by applying standard hydrologic methods. The mean and maximum river discharges for the sub-basins of the river ranged from 11 to 33 m^3s^{-1} and from 118 to 210 m^3s^{-1}, respectively, with the peak river discharge at the main Tiva branch being 270 m^3s^{-1}. The study shows that there is a significant relationship between the variability of streamflow and the variability of salinity, conductivity and TDS in the river. The relationships between streamflow and salinity were best represented by power functions rather than linear regression functions. The relationships were negative so that the levels of salinity, conductivity and TDS decreased with an increase in river discharge. Salinity, TDS and conductivity were also inversely correlated to turbidity. An increase in turbidity corresponded to a decrease in conductivity and hence salinity and TDS. The low conductivity at high streamflow conditions were attributed to the dilution effect of increased volume and also by the presence of high proportion of non-conductance organic and inorganic materials such sand and clay. The highest TDS, conductivity and salinity values were measured during the low flow (baseflow) conditions and the concentrations were lowest during high streamflow conditions. It is postulated that the high concentrations were a result of high evapotranspiration and seepage of subterranean water from bank storage and groundwater aquifers, and that low concentrations were a result of dilution and flushing effect of high streamflow. Inter-subbasin variations in the levels of salinity were attributed to differences in landuses, lengths and sizes of the sub-basins. The effects of upstream irrigation were evident in one of the main sub-basins-Mwitasyano river where the highest salinity levels (max: 3.4%; mean 1.1%) were measured. The total salt flux from Upper Tiva river basin was estimated to be 100,344 tonnes.yr^{-1} with basin salt production rate of 27.87 tons.m^{-2}.yr^{-1}. This salt flux was attributed to the nature of the basement complex metamorphic rocks (e.g. Kankur limestone) through which the river drains. The influence of irrigation upstream was noted to be important in the Mwitasyano sub-basin that contributed 61% of the total salt load. The study emphasizes the need for water resources and agricultural development programmes in the semi arid Tiva River Basin to promote sustainable irrigation and landuse practices. It is suggested that construction of water reservoirs in the Tiva basin would help in controlling salinity levels in the river.

Keywords: Tiva River; Salinity; Total Dissolved Solids (TDS); Streamflow; Salt fluxes; Kenya

1. Introduction

Seasonal rivers in arid and semi arid lands (ASALs) of Africa are important sources of water to communities and their livestock. However, despite the important role played by seasonal rivers in such lands, few studies have been undertaken to unravel their hydrologic and water quality characteristics (Kitheka, 2013 & 2014). There is thus scanty of data and information on river discharges and material (including nutrient, sediment and salt) fluxes in seasonal rivers of Sahelian Africa. The contribution of African seasonal rivers in terms of global nutrient and material fluxes is therefore little understood, since most of the hydrological studies have focused on perennial river systems (Ohowa et al., 1997; Busulwa and Bailey, 2004; Waziri and Ogugbuaja, 2010; Waziri and Ogugbuaja, 2012; Elmoustafa, 2013; Kitheka, 2013 & 2014). Seasonal rivers in semi arid lands are unique in that they usually flow for relatively short period during rainy season. Data and information on their hydrology are required to advice on the water resources and agricultural development programmes. This is becoming critical as a result of climate change and also due to current programmes that are aimed at opening up arid and semi arid lands for development. Seasonal rivers could be the only reliable source of water that can be used to develop ASALs.

Most of the studies on seasonal rivers in Kenya have focused on water pollution, soil erosion and nutrient fluxes (see Kithia, 1997; Ohowa et al., 1997). Some studies on Kenya have shown that some seasonal rivers at the coastal basin are characterized by high nutrients loads in rainy season as compared to dry season (Ohowa et al., 1997). Recent studies on Kenya's largest river-Tana have demonstrated the effects of modification of streamflow and sediment load as a result of damming of the river in the Upper Tana Basin (Kitheka, 2013 & 2014).. However, despite the impact of damming, Tana river still receives substantial sediment load from seasonal streams such Tiva river that drains into the lower Tana Basin (Figure 1a). To our knowledge, no studies have been undertaken on salt fluxes in rivers of Kenya. However, past studies on salinity conducted elsewhere have shown that the main driving forces acting in shaping seasonal variation of salinity include low natural drainage density of the catchment, which limits the salt loads induced by the natural runoff processes, and the runoff in the catchment area which promote dissolved salt dilution during the high-flow period (cf. Kaabata *et al*., 2012).

Tiva river is one of the seasonal rivers that forms part of the larger Tana River Basin-the largest river system in Kenya (Figure 1a). Tiva river basin receives highly erratic and seasonal rainfall which is one of the major factors limiting community access to water, agricultural production and food security in Kitui and Tana River Counties where it traverses (see also Lasage et al., 2008). The seasonal river and its tributaries has been source of water for majority of the people and livestock in Kitui County for many generations. In order to address the chronic shortage of water to rural communities in the county, an effort is now being focused on the exploitation of water resources of Tiva river through development of sand dams (Beimers et al., 2001a-b; Burger et al., 2003; Bossenbroek and Timmermans, 2003: Munyao et al., 2004; Puttemans, 2004; Borst and De Haas, 2006; Lasage et al., 2008). However, such development programmes needs to be based on the assessment of suitability of water for domestic, livestock and agricultural uses. Such an approach can safeguard public health, protect fragile semi arid lands soil (e.g. from salinisation, sodification, etc) and enhance water security for the local communities. In the past, there have been little concern on the water quality of seasonal rivers targeted for development in ASALS. This lack of concern was partly due to the assumption that seasonal rivers in marginalized ASALs are not subject of major anthropogenic influences that can cause significant pollution. This study shows that while anthropogenic drivers of pollution may not be critical in ASALs, natural factors associated with hydrogeo-chemical and catchment characteristics are important determinant of water quality of seasonal rivers such as Tiva. However, it is important to note that anthropogenic influences are also progressively becoming important in ASALs of Kenya and cases of water pollution due to municipal wastewater discharges have been reported in Kitui (Abila et al., 2012; Karanja et al., 2015).

This research was partly motivated by the need for baseline studies to establish the levels of basic water quality parameters (e.g. salinity, conductivity, TDS) in seasonal rivers draining ASALs of Africa. Such studies will provide data and information against which future changes due to development activities can be determined. This is important in view of rapid population growth and expansion in ASALs and recent campaigns to open up ASALs for development in Africa. Establishment of the levels of key physico-chemical parameters and their associated natural and anthropogenic drivers is equally important in that these parameters are important determinant of water security, public health and agricultural crop production. Consumption of water of unquestionable quality is associated with various waterborne and water related diseases. Also, use of water with high levels of salinity in small-scale irrigation leads to deterioration of soil quality and subsequently leads to reduced crop production in ASALs (cf. Puttemans, 2004). High salinity in rivers can also cause major damages such as corrosion and plugging of pipes and water fixtures in housing and industry (U.S. Department of the Interior, 2011). Such damages can impose high operation and maintenance costs to rural water supply schemes in ASALs that are often run by communities with limited resources (see also Lasage et al., 2008).

This study focused on the measurement of salinity, total dissolved solids (TDS) and conductivity in the Tiva river sub-basin. These physico-chemical parameters have been used describe the overall water salinity in rivers. Although conductivity is of little human concern, high conductivity is usually an indication of existence of a source of dissolved ions and is therefore a good indicator of other water quality problems in rivers (Bhattet al., 1999; Vaishal and Punita, 2013). There is also a relationship between the concentration of dissolved solids in water and salinity. The high amount of dissolved solids means high concentration of ions in water and this causes high salinity (Bhattet al., 1999). Some studies have noted that high levels of conductivity and cations are the product of decomposition and mineralization of organic materials (cf. Abida, 2008). Conductivity therefore provides a clear view of the total ionic strength and extent of salinity and helps in assessing the level of TDS in a water body (APHA, 1992; Massdam and Smith, 1994). TDS is an indicator of the amount of dissolved mineral salts in water and is usually composed mainly of carbonates, bicarbonates, chlorides, phosphates and nitrates of calcium, magnesium, sodium, potassium and manganese, organic matter, salt and other particles (Mahananda, 2010). At high flows, the TDS concentrations is diluted by surface runoff and for most rivers there is an inverse correlation between discharge rate and TDS concentration (Charkhabi and Sakizadeh, 2006; Srivastava et al., 2011). Some but not the entire dissolved solids act as conductors and contribute to the conductivity level in water. River water with high TDS are unpalatable and potentially unhealthy (Vaishal and Punita, 2013). The WHO drinking water standard for TDS is 500mgl^{-1} and water with greater concentration is unpalatable. Excessive TDS in water imparts a bad taste in water due to mineralization of various salts. A TDS concentration >2,000mgl^{-1} has been reported to produce a laxative effect as a result of the presence of magnesium sulphate and some sodium sulphate (Kumaraswamy, 1991, Dembere 1998). Sodium affect the cardiac part and women suffer toxemia during pregnancy. The maximum permissible limit of TDS in drinking water is 1,000mgl^{-1} (WHO). For irrigation, maximum permissible limit of TDS is 500mgl^{-1} and above this limit, salinity has detrimental effect on crop production. Salinity is closely related to TDS and conductivity. An increase in TDS and conductivity therefore leads to a corresponding increase in salinity. Past studies elsewhere have shown that the concentration of salinity usually decrease in rainy season as a result of dilution of dissolved ions by the surface runoff (cf. Srivastava et al., 2011).

This study sought to establish the salinity fluxes in the semi arid Tiva River Basin in Eastern Kenya. The specific objectives of the study were; (i) provide baseline data and information on the levels of salinity, TDS and conductivity in a typical seasonal river; (ii) determine the influence of streamflow on the variability of salinity, conductivity and TDS and (iii) establish the magnitude of salt flux in a typical seasonal river.

2. Description of the Study Area: Tiva River Basin

2.1 Geographical Characteristics

Tiva River Basin is found in lower Eastern Kenya and is one of the sub-basins of the Tana Basin-the largest river system in Kenya draining into the Indian Ocean (Figure 1a). The total surface area of the basin determined using My Google Map Length and Area Computation Tool is 18,150 km^2 and length of the river from its headwaters in Kitui County to the lower Tana basin near Garsen is 380km. The upper Tiva basin covers a surface area of 3,600 km^2. The width of the main river varies from about 40m in the upper basin to 100m in the middle reaches and <50m in the lower zone. The topography of the basin can be divided into an upland and lowland zone. The upland zone includes the Yatta Plateau and the Kitui Mountain Ranges in the north-west of the basin. Elevations in the upland area vary between 600 and 1800 m above sea level. The lowland area is found to the east of the basin and this area covering the majority of the sub-basin is a gently eastward-sloping peneplain with elevation varying from 400 to 600 m above sea level. Few isolated inselbergs are found in this zone (Borst and de Haas, 2006).

The climate in the sub-basin is generally hot and dry with erratic and unreliable rainfall typical of arid and semi-arid climatic zones (Lasage et al., 2008). There are two rainy seasons, one from March to May (long rains) and one from October to December (short rains) (Lasage et al., 2008). The rest of the year is hot and dry. The total annual rainfall average is between 750 and 1150 mm with 40/60 percent reliability. Air temperature ranges between 16^{o}C and 34^{o}C with mean maxima of 28^{o}C and minima of 22^{o}C. The average temperature is 24^{o}C (Horst and de Hass, 2006). The prevailing winds are the north and south easterly monsoon winds. Potential evaporation is high, 1500-1600 mm.yr^{-1}, largely exceeding the mean annual rainfall of about 1000mm.yr^{-1} in the headwaters of the basin (Lasage et al., 2008). Runoff generation is high due to low infiltration capacity of soils (see also Ngigi et al., 2005).

2.2 Vegetation Cover

Vegetation in the Tiva basin is characterised by scrublands and wooded bushland. In the upper region of the basin, the Kitui hilltops are usually characterised by upland dry forest ecosystems dominated by *Drypetes*, *Combretum*, *Vepris* and *Croton* species (Lind & Morrison, 1974). The lower zones of the Kitui hills are covered with Acacia-*Commiphora* and *Strychnos*-*Combretum* or *Commiphora* bushland vegetation type (Lind & Morrison, 1974). At higher altitudes close to 1200 m, the vegetation is dominated by *Croton megalocarpus*, *Rawsonia lucida*, *Manilkara discolor* and *Drypetes* species, resulting in semi-evergreen dry upland forests. In the lowland zone, beow 500m asl, the vegetation is mainly *Acacia -Commiphora* complex.

2.3 Geology and topography

The Tiva sub-basin is within the Mozambique belt and is generally occupied by the basement complex system consisting mainly of metamorphic rocks (Nyamai et al., 2003). The rocks are dominated by massive metamorphic granulites which are highly impermeable. These are usually composed quartz and feldspars, red garnets and pyroxenes or less. The rock outcrops are composed of metamorphic granulites composed of quartz and feldspars, mafic pyroxenes, biotite and red almandine garnets (cf. Nyamai et al., 2003). The river channel is usually sandy with well sorted and mature sand without or with minimal silt/clay content and with water being retained in their sub-surface pores. Most of the river courses are composed of metamorphic granulites and gneisses. Mafic granulites rich in garnets and black heavy minerals, iron ore and pyroxenes have weathered into deep red soils rich in black heavy mineral sands. In some places are found well foliated biotite gneiss which allows some infiltration of rainwater into the ground. Kunkar limestone and white patches of sodium chloride are common along the river banks making the water slightly brackish, particularly during periods of low flow.

The lower part of the sub-basin is found in the lower Tana Basin in lowlying area with elevation less than 500m asl. This region is covered with the Quaternary sediment deposits. The river forms a large inland delta (36km long and 4km wide A= 180km^2 Ndarapo Swamp) in its lower course in Tana River County and subsequently flows to Tana through Laga Kokani where it joins the river in the area north of Garsen (Figure 1a). The middle zone of the river before it forms the inland delta appears to be covered by degraded sodic lumic vertisols. High sodicity of soils in the lowlying basin perhaps accounts for whitish patches around the delta that can be discerned from the satellite image (Figure 1b).

2.4 Sub-basins and drainage

The main tributaries of the Tiva river occurs in its upper basin. These are Kauwi, Kalundu, Nzeeu, Mikuyuni and Mwitasyano, among others that flows only during rainy seasons. The seasonal rivers are characterised by low flows (base flows) in dry season and high flows during rainy seasons, i.e. April-May and November-December. Most of the ephemeral streams generally become dry within one month after the rainy season (cf. Borst and De Haas, 2006).

2.5 Socio-economic characteristics

The population within the basin is estimated to be 1,060,000. The population density is relatively low being about 33 people per km. Rainfed agriculture is an extremely challenging activity given the sporadic and low rainfall in the basin which is often poorly distributed on spatial-temporary basis. The region particularly Kitui County has enormous potential for development of mining industries in view of its vast mineral resources. Plans are underway to commence mining of coal, iron ore and marble (limestone). The development of mining industry is expected to affect water quality in the Tiva sub-basin. Livestock grazing by Orma community is the predominant socio-economic activity in the dry lower zones of the Tiva sub-basin that extends into the Tana river County. However, in the upper zones, major landuse activities are mixed farming characterised by cultivation of crops and livestock grazing. Most of the farms are small-scale mixed farms <3ha, with the exception of the upper parts of the basin (Mwitasyano and Kauwi sub-basins) where large-scale cultivation of crops is common landuse activity in addition to livestock grazing.

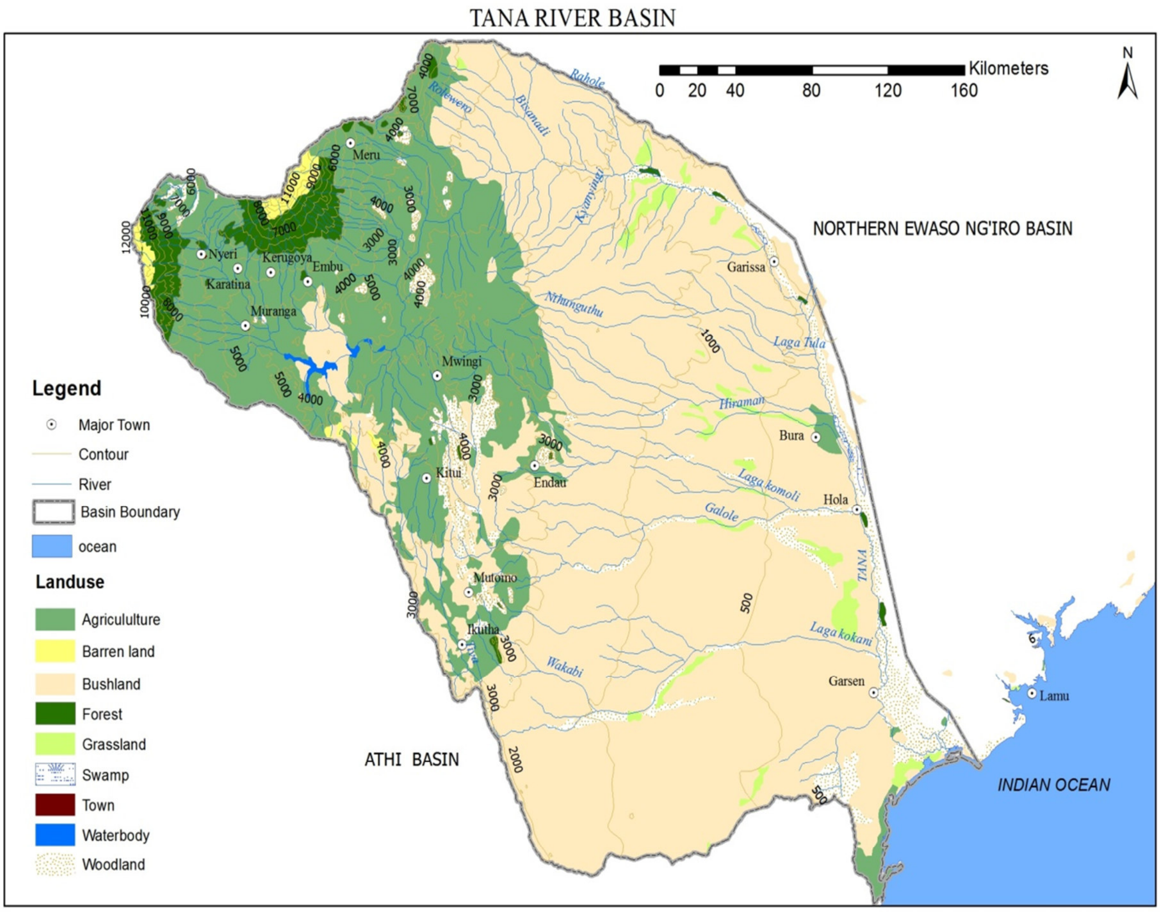

Figure 1a: Map of Tana Basin showing Tiva river sub-basin to south and flowing into the Tana river as Laga Kokani in the area north of Garsen Town. The elevations above sea level are expressed in feet.

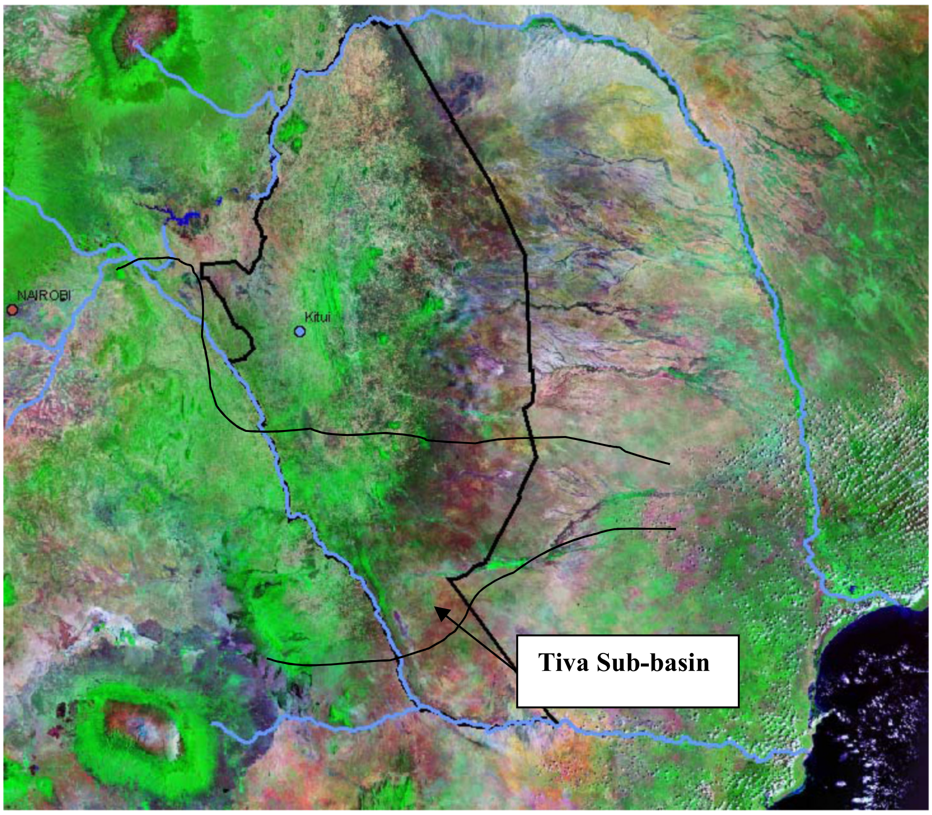

Figure 1b: Satellite image of southern region of Kenya including Kitui region and Tiva Sub-basin (Source: USGS and NASA). The border to the west is the Yatta Plateau that forms the divide with the Athi river.

3. Methodology

3.1 Streamflow measurements

This study was undertaken within the main Tiva river and also in seasonal rivers draining into the river. These include Mwitasyano, Kauwi, Nzeeu and Kalundu. Sampling stations were established within each of the sub-basins of the Tiva river system. In these stations, measurements of river discharges and physico-chemical parameters were undertaken in the period between March 2013 and December 2015.

River discharges were measured on weekly and monthly basis at sampling stations using standard hydrological procedures as described in Linsley *et al*. (1998). River discharges were determined using the cross-sectional-area velocity approach (see also Chapman, 1996 and Bartram and Ballance, 1996). Manning roughness coefficient was computed according to equation 1.

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \quad (1)$$

Where: Q = maximum discharge in riverbed section (m^3/s); n = Manning roughness coefficient of riverbed; A = wetted cross-sectional area (m^2); P = wetted perimeter (m); R = hydraulic radius (m) = A/P, and, S = slope of riverbed (m/m).

River discharge data were correlated with the data on salinity, conductivity and TDS in each of the sampling stations. The data was also used to compute monthly and annual salt flux rates. The stream morphology was determined through measurement of the gradient, width and depth of the river channel. The sediment characteristics were based on the field observations and particle size analysis of sediment samples.

3.2 Measurement of physic-chemical parameters

The main water quality parameters that were measured in the field are turbidity, temperature, total dissolved solids concentration, conductivity and salinity. Turbidity was measured using Hanna Instruments HI93703 Microprocessor turbidity meter capable of measuring turbidity in the range of 0 to 1000FTU. TDS, salinity, temperature and conductivity were measured using Martini Instruments Mi306 EC/TDS/NaCl/Temperature meter.

The study was undertaken in both dry and wet seasons. During rainy season, the frequency of sampling was daily in order to capture highly variable streamflow. During dry seasons, measurements of baseflow and sampling of physico-chemical parameters was undertaken once every week and occasionally once every month later in dry season. Because low flows were more frequent as compared to high streamflows, our measurements tended to have a greater concentration of low flow measurements as opposed to high flow ones.

3.3 Analysis of hydrologic data

The data analysis involved regression and correlation analysis that were performed to establish the relationship between streamflow and salinity, conductivity and TDS and other control variables (e.g turbidity). Correlation coefficient (r) and Coefficient of Determination (R^2) were generated using Microsoft Excel Statistical Analyses Tools (p = 0.05). The best regression curves for the relationships were fitted using either linear, logarithmic or power functions depending on the strength of the relationship as represented by R^2 coefficient. Also, we determined standard deviations, mean values and maximum and minimum values of the measured parameters.

3.4 Determination of salt fluxes

The salt fluxes at sub-basin level were based on the results of TDS measurements. The mean discharge-weighted TDS were obtained by taking the average of the concentration values C (TDS) obtained for each interval

$$C = \sum_{I=1}^{N} C_i \qquad (2)$$

All TDS concentrations measured across the cross-section were summed up and divided by the sample size. River salt flux rates were determined by multiplying river discharges (Q) with the TDS concentrations (C) using equation 3. The salinity fluxes (Φ) were derived from the measurements of both river discharge (Q) and TDS concentrations (C), between time t and t_a according to equation 3.

$$\Phi = \int_{ti}^{t2} C(t)Q(t)\delta t \qquad (3)$$

The TDS concentrations (C) in the river occurring during the time between two samplings were extrapolated according to constant concentration and constant flux approaches according to equation 4 as described in Chapman (1996)

$$\Psi = Q_j C_J \qquad (4)$$

Where Q_j is the mean river discharge during the time interval δt_j, Ψ is the TDS concentration during the interval and C_j is the TDS concentration at time t_i which is assumed to be constant during a time interval δt_j. The total salt flux rate was then computed according to equation 5.

The total salt flux $\Phi = \sum \Psi$ (5)

4. Results

4.1 Variation of streamflow

Tiva River Basin drains mainly from Kitui Mountain Ranges that are part of the Mozambique Basin Basement Complex composed of a variety of weathered metamorphic rocks (cf. Nyamai et al., 2003). The mountains are essentially anticlines rising to an altitude of 1800m a.s.l in Kitui Central in the upper parts of the basin. The major tributaries draining into the main Tiva river from the mountains are Kalundu, Nzeeu and Kauwi rivers. Mwitasyano river - a major tributary further to the north also receives flow contribution from the volcanic Yatta Plateau and Yatta Canal as irrigation return flow.

The flow of Tiva river is influenced by rainfall distribution in the upper parts of the basin in Kitui County. There are normally two periods when there is flow in the river, namely the long and short rainy periods. Rainfall is normally of relatively greater magnitude and is well distributed in most parts of the basin in the period between October and December. During the south–east monsoon in the period between March and May, rainfall amounts are relatively lower and rainfall is generally poorly distributed in the basin. The significant river discharges occur in the October-December period (short rains) and in the March-May period (long rains). The dry periods when there is no streamflow in the river are mainly January-March and June-September periods.

There is a significant variability in the river discharge rates of the sub-basins that form the larger Tiva basin as a result of influences of catchment sizes, morphology and landuse characteristics. Based on data collected in the period between March 2014 and December 2015, the mean discharges for the main tributaries of Tiva river range from 11 to 33 m^3s^{-1}. The maximum discharges for the main tributaries ranged between 118 and 210 m^3s^{-1}. The peak river discharge at the main Tiva River branch was 270 m^3s^{-1}. It must however be noted that streamflows < 0.4 m^3s^{-1} are more frequent in the main branch of the river. The flow hydrograph generated for one of the sub-basins showed that streamflow is characterized by relatively steep rising and falling limbs, short duration peaks and long recession period (Figure 2). The relatively long recession period indicates return of water into the main channel from bank storage and groundwater aquifers bordering the river.

The low streamflows for most of the sub-basin streams were more frequent as they occurred >75% of the time as compared to high flows that occurred in < 15% of the time. The features are consistent with the characteristics typical seasonal rivers in the semi-arid regions. For all sub-basins, the high streamflows were characterized by relatively high turbidity that reached 1000 FTU. This was attributed to high rates of soil erosion in the basin and consequently high sediment load (see also Kithia, 1997; Kitheka, 2014).

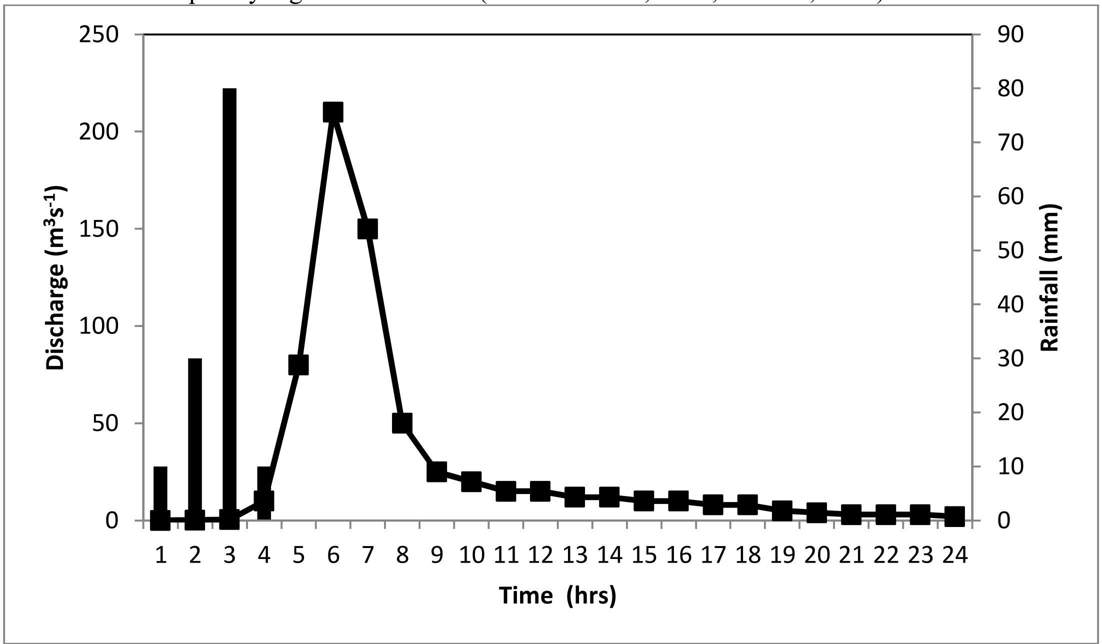

Figure 1: Kalundu river streamflow hydrograph based on measurements conducted on 28-29th March 2013. The long recession period is evident in the stream.

4.2 Variation of salinity as a function of streamflow

The salinity in the sub-basins of Tiva river shows significant variability and streamflow seemed to play an important role in the variability. During dry season in Mwitasyano river with streamflow < $0.1 m^3s^{-1}$, conductivity and TDS were 1,159 $\mu S.cm^{-1}$ and 2,324 mgl^{-1}, respectively, which are way above the WHO Drinking Water Standards (WHO, 1993, 2006 and 2008). However, during wet season with streamflow > 2 m^3s^{-1}, the conductivity and TDS ranged 217 - 491 $\mu S.cm^{-1}$ and108-246 mgl^{-1}, respectively. The wet season salinity ranged 0.4-0.8% and turbidity ranged 137-1000 FTU.

The variability in salinity was related to streamflow and therefore there was a rapid change in salinity flowing a decrease in river discharge. For instance, on 1st April 2013 with the streamflow rate of 118 m^3s^{-1}, the conductivity, TDS and salinity were 217.7 $\mu S.cm^{-1}$, 108.1 mgl^{-1} and 0.4%, respectively. However, the cessation of river discharge in the following day (1st May 2013) led to an increase of conductivity, TDS and salinity to 1,786 μScm^{-1}, 894 mgl^{-1} and 3.45%, respectively.

The same patterns were observed in the case of Kauwi river. In this river, on 28th March 2013, we observed that when streamflow was 168 m^3s^{-1}, the levels of conductivity, TDS and salinity were generally low being 82$\mu S.cm^{-1}$, 40mgl^{-1} and 0.1%, respectively. However, following cessation of streamflow on 1st May 2013, the conductivity, TDS and salinity increased considerably to 400 $\mu S.cm^{-1}$, 200 mgl^{-1} and 0.8%, respectively

In Nzeeu sub-basin, on 28th March 2013 we observed that when the river discharge was 141m^3s^{-1}, the levels of conductivity, TDS and salinity were generally low being 63 $\mu S.cm^{-1}$, 31.4 mgl^{-1} and 0.1%, respectively. However, following cessation of streamflow on 1st May 2013, the levels of conductivity, TDS and salinity increased to 198 $\mu S.cm^{-1,}$ 98 mgl^{-1} and 0.4%, respectively. There are also day to day variations in the levels of salinity that are a result of day to day variations in streamflow which in turn is a response to the day to day variations of rainfall. For instance, on 29th March 2013 when the streamflow dropped to 5.95 m^3s^{-1}, the levels of conductivity, TDS and salinity increased to 159 $\mu S.cm^{-1}$, 79.5 mgl^{-1} and 0.3%, respectively

In Kalundu sub-basin, the high flows (210 m^3s^{-1}) experienced on 28th March 2013 led to relatively low levels of conductivity, TDS and salinity that were 81 $\mu S.cm^{-1}$, 40 mgl^{-1} , 0.1%, respectively. However, 31st March 2013 following reduction in streamflow to 1.8 m^3s^{-1}, levels of conductivity, TDS and salinity increased to 156 μScm^{-1}, 78 mgl^{-1}, 0.3%, respectively. On 1st May 2013, when the stream was low (0.2 m^3s^{-1}), the levels of conductivity, TDS and salinity were generally high being 246 $\mu S.cm^{-1}$, 123 mgl^{-1}, 0.4%, respectively.

In the main Tiva river branch which receives streamflow from Nzeeu, Kalundu and Kauwi rivers, we observed similar patterns. For instance on 28th March 2013, the high streamflow rate of 182 m^3s^{-1} resulted in relatively low levels of conductivity, TDS and salinity that were of the order 112 µS.cm^{-1}, 80 mgl^{-1}, 0.2%, respectively. Following reduction of streamflow to < 0.01 m^{3}s^{-1} on 1st May 2013, the levels of conductivity, TDS and salinity increased to 455 µS.cm^{-1}, 227 mgl^{-1}, 0.9%, respectively. In December 2015 during low streamflow discharge of 0.4 m^{3}s^{-1}, the conductivity, TDS and salinity were relatively high being 534 µS.cm^{-1}, 263 mgl^{-1} and 1.0%, respectively. Thus, it can be concluded that the high streamflows were generally characterized by relatively low conductivity, TDS and salinity. There is in generally a rapid increase in salinity following cessation of high streamflow in the Tiva river which probably indicates the influence of water entrapment within the river channel including returnflow from bank storage and groundwater aquifers.

4.3 Variations of salinity, TDS and conductivity in Nzeeu and Kalundu sub-basins

Table 1 shows the mean, maximum and minimum vales of various physico-chemical parameters associated with salinity that were measured in Nzeeu and Kalundu sub-basin rivers. The mean salinity and TDS for Nzeeu sub-basin were 0.3% and 76.3 mgl^{-1}, respectively. The mean salinity and TDS for Kalundu river were 0.3% and 86.7 mgl^{-1}, respectively. The lowest salinity and TDS were recorded in periods of maximum river discharges. On the other hand, the maximum salinity and TDS were recorded in periods of low river discharges and during periods of baseflow consisting partly of water trapped within the river channel in addition to effluent flows that originates from bank storage and groundwater aquifers.

The mean salinity and TDS including the streamflow characteristics were generally similar for the two sub-basins that originates from a forested Kitui hills at an elevation ranging 1400-1800m asl. This is despite the fact that Kalundu river recorded significant higher maximum river discharge as compared to Nzeeu river. This is attributed to the differences in landuse characteristics in the two sub-basins. Kalundu sub-basin is more degraded and is characterized by more extensive small-scale cultivation as compared to Nzeeu sub-basin.

Table 1: The statistical values for various physico-chemical parameters measured at Nzeeu and Kalundu rivers.

	Turb (FTU)		**Sal (%)**		**Cond (µS.cm^{-1})**		**TDS (mg.l^{-1})**		**Q_f (m^{3}s^{-1})**	
	Nzeeu	Kalundu	Nzeeu	Kalundu	Nzeeu	Kalundu	Nzeeu	Kalundu	Nzeeu	Kalundu
Mean	452.4	383.8	0.3	0.3	152.8	173.9	76.3	86.7	11.3	13.1
Max	1000	1000	0.4	0.5	234.4	262.9	117.1	131.5	141.8	210.6
Min	53	47	0.1	0.1	59	81	29.5	40	0.1	0.2
STD	340.7	314.8	0.1	0.1	51.7	57.4	25.8	28.5	28.6	43.3

4.4 Variations of salinity, TDS and conductivity in the Tiva sub-basins

Table 2 shows the data on the various physico-chemical parameters measured at the Tiva sub-basins at the upper and lower sections of the river (Kabati and Kwa Vonza sampling stations). The mean salinity for the main branch of Tiva river was 0.3% while TDS ranged between 88 and 92 mgl^{-1}. The maximum salinity and TDS were 0.8% and 225 mgl^{-1}, respectively. These occurred during dry season when river discharges were <0.01 m^{3}s^{-1}. The lowest salinity, conductivity and TDS were measured during periods of high river discharge ranging between 137 and 216 m^{3}s^{-1} with the turbidity averaging 799 FTU.

Table 2: The statistical values for various physic-chemical parameters at Tiva near Kabati and Tiva at Kwa Vonza

	Turb (FTU)		**Sal (%)**		**Cond (µS.cm^{-1})**		**TDS (mg.l^{-1})**		**Q_f (m^{3}s^{-1})**	
	Tiva (Kabati)	Tiva (Upper)	Tiva (Kabati)	Tiva (Upper)	Tiva (Kabati)	Tiva (Upper)	Tiva (Kabati)	Tiva (Upper)	Tiva (Kabati)	Tiva (Upper)
Mean	798.75	680.3	0.3	0.3	175.4	183.8	88.1	92.4	32.6	54.6
Max	1000	1000	0.8	0.9	441	455	223	227	136.5	216
Min	84	13.7	0.1	0.1	81	84	40.5	41.4	0	0
STD	362.9	308.3	0.2	0.2	121.7	117.8	61.6	58.3	56.1	77.4

4.5 Variations of salinity, TDS and conductivity in Kauwi and Mwitasyano sub-basins

Table 3 shows the key statistical parameters for the Kauwi and Mwitasyano rivers draining into the Tiva river from the northern parts of the basin in an area with extensive large-scale cultivation and to some extent irrigation. The mean salinity and TDS for the two rivers were not significantly different. However, the maximum salinity and TDS were significantly difference. Mwitasyano river had the highest salinity and TDS of 3.4% and 894 mgl^{-1}, respectively, as compared to the values for Kauwi that were 0.8% and 200 mgl^{-1}, respectively. These differences could be attributed to the differences in the maximum river discharges experienced in the two rivers. Kauwi river experienced much higher river discharges as compared to Mwitasyano river during the period of measurements. However, Kauwi river tended to experience the lowest concentrations of salinity and TDS during high flow conditions. On the other hand, Mwitasyano river experienced the highest concentrations during low flow conditions.

Table 3: The statistical values for Kauwi river (Kabati) and Mwitasyano river

	Turb (FTU)		Sal (%)		Cond ($\mu S.cm^{-1}$)		TDS ($mg.l^{-1}$)		Q_f (m^3s^{-1})	
	Kauwi	Mwita	Kauwi	Mwita	Kauwi	Mwita	Kauwi	Mwita	Kauwi	Mwita
Mean	674.1	467.2	0.33	1.1	164.2	727.7	83.4	364.0	30.3	32.60
Max	1000	1000	0.8	3.4	400	1786	200	894	168	118.13
Min	6.5	0.8	0.1	0.4	82	217.7	40	108.1	0.01	0.01
STD	423.7	476.1	0.23	1.4	112.4	714.9	55.4	358.1	59.9	57.18

Relationship between streamflow and salinity

There is a relationship between variations of streamflow and salinity in various streams draining the sub-basins of the Tiva river. Figures 3a, 5a and 7a shows the relationship between streamflow and salinity in the Nzeeu, Kalundu and Tiva rivers. The relationships are inverse so that an increase in streamflow results into a decrease in salinity, and the vice versa is true. Thus high streamflows are characterized by relatively low salinities as compared to low flows that are characterized by relatively high salinity. For Nzeeu, Kalundu, Tiva and Mwitasyano sub-basins, the relationships were relatively strong with correlation coefficients r being 0.55, 0.83, 0.88 and 0.96, respectively. The relationships were best represented by the regression power functions as opposed to linear regression functions. However, the extent to which streamflow can be used to predict variations of salinity in Nzeeu river was limited by the low coefficient of determination R^2 of 0.30 indicating that variations in streamflow explained salinity variations by 30% . The R^2 values were however much higher for Kalundu, Tiva and Mwitasyano sub-basins; 0.69, 0.78 and 0.93, respectively. This means the power functions derived for the relationship between streamflow and salinity in Kalundu, Tiva and Mwitasyano sub-basins can be used to predict salinity quite effectively. The streamflow directly influences salinity such that level of salinity reduces as the streamflow increases. For the most part, higher streamflows dilute salinity, a finding that has also been reported in the case of Colorado river in the US (U.S. Department of the Interior, 2011).

Relationship between streamflow and TDS

There is also a strong relationship between streamflow and TDS concentration in the sub-basin rivers that drains to the larger Tiva river. Figures 3b, 5c, 7c shows the results of the relationship between streamflow and TDS concentration in Nzeeu, Kalundu and Tiva sub-basins. The relationships were also relatively strong with the r values of 0.44, 0.79 and 0.86 and 0.99 for Nzeeu, Kalundu, Tiva and Mwitasyano rivers, respectively. The relationships are inverse so that an increase in streamflow leads to a decrease in TDS concentration. The high streamflows were characterized by relatively low TDS concentrations as compared to low streamflows that were characterized by high TDS concentrations. The relationships were also represented best by regression power functions. The extent to which streamflow can be used to predict TDS concentrations using the regression power functions was found to be good in the case of Kalundu river (R^2=0.62), Tiva (R^2=0.75) and Mwitasyano river (R^2=0.99). For Nzeeu river, the variability of streamflow explained variability in TDS concentrations by only 19% (R^2 = 0.19) with the implication that the derived regression power function cannot be used to predict variability of salinity in the river. The high TDS concentrations during the low streamflow conditions were attributed to accumulation of mineral salts as a result of seepage of water from bank storage and groundwater aquifer as well as evaporation of water in the sandy river channel.

Relationship between streamflow and conductivity

There is a relationship between streamflow variability and the variations of water conductivity in all sub-basins of the larger Tiva Basin. Figures 3c, 5b and 7b shows the plots of the relationship between streamflow and conductivity in Nzeeu, Kalundu, and Tiva sub-basins. The relationships were inverse with relatively strong r values of 0.79, 0.90 and 0.97 for Kalundu, Tiva and Mwitasyano rivers respectively. The r value for Nzeeu was however low (r = 0.44). The relationships were also inverse indicating that conductivity declines as streamflow increases. The highest conductivity values were measured during periods of low streamflow conditions with water entrapped within the sandy river channel. The relationships were also best represented by regression power functions, with the extent to which streamflow can be used to predict conductivity varying from one sub-basin to the other. The R^2 values were also relatively high for Kalundu, Tiva and Mwitasyano rivers (R^2 values of 0.62, 0.80, 0.93, respectively) meaning that the regression power functions derived for these sub-basins can be used predict variations of conductivity. The R^2 value for Nzeeu river was relatively low (R^2= 0.20) thus limiting the extent to which the derived equation can be used to predict variations of conductivity in the river.

Relationship between salinity and turbidity

There is a relationship between turbidity and salinity in all the sub-basins of the larger Tiva basin. Figures 4, 5 and 8 show the plots of the relationship between turbidity and TDS in Nzeeu, Kalundu and Tiva sub-basins. The relationships were inverse so that an increase in turbidity was associated with a decrease in TDS and subsequently salinity and conductivity. Thus, periods of high streamflows with highly turbid water were characterized by relatively low TDS concentrations and conductivity. Periods of low turbidity were associated with low streamflow conditions. However, TDS, salinity and conductivity tended to be high during the low flow periods. The relationships were best represented by linear regression equations with the exception of Kalundu river where a logarithmic regression function described the relationship more satisfactorily. The *r* values for Nzeeu, Kalundu, Tiva and Mwitasyano rivers were 0.88, 0.87, 0.87 and 0.93, respectively. The equations that were derived from the relationships had relatively high R^2 values of 0.77, 0.84, 0.75 and 0.93 for Nzeeu, Kalundu, Tiva and Mwitasyano rivers, respectively.

The variations of streamflow have an important influence on the variability of turbidity. During high flow conditions, the streams receive highly turbid runoff derived from degraded land. This explains the high turbidity (700-1000 FTU) that was measured in streams during periods of high flows. Turbidity during low flow conditions were of the order 0.7 FTU indicating presence of relatively clear water. Observations also showed that during periods of high river discharges, the sediment load consisted mainly of suspended sediment load with high proportion of clay, sand and silt (Kitheka, 2013 and 2014). There is thus high concentration of materials that do not conduct electricity more effectively, Thus, in addition to the dilution effect of increased freshwater volume, the low conductivity during high flows can also be attributed to the presence of high proportion of non-conductance inorganic materials such as clay, sand and silt (se also Bhattet al., 1999; Vaishal and Punita, 2013).

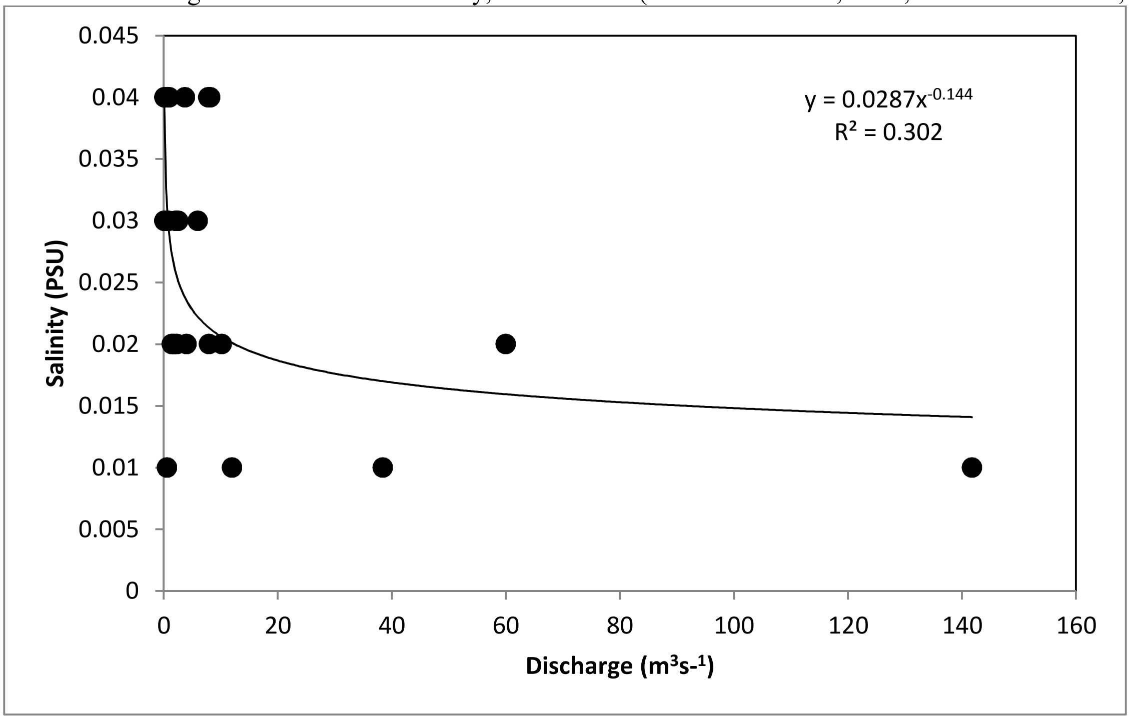

Figure 3a: Relationship between streamflow and salinity in Nzeeu river.

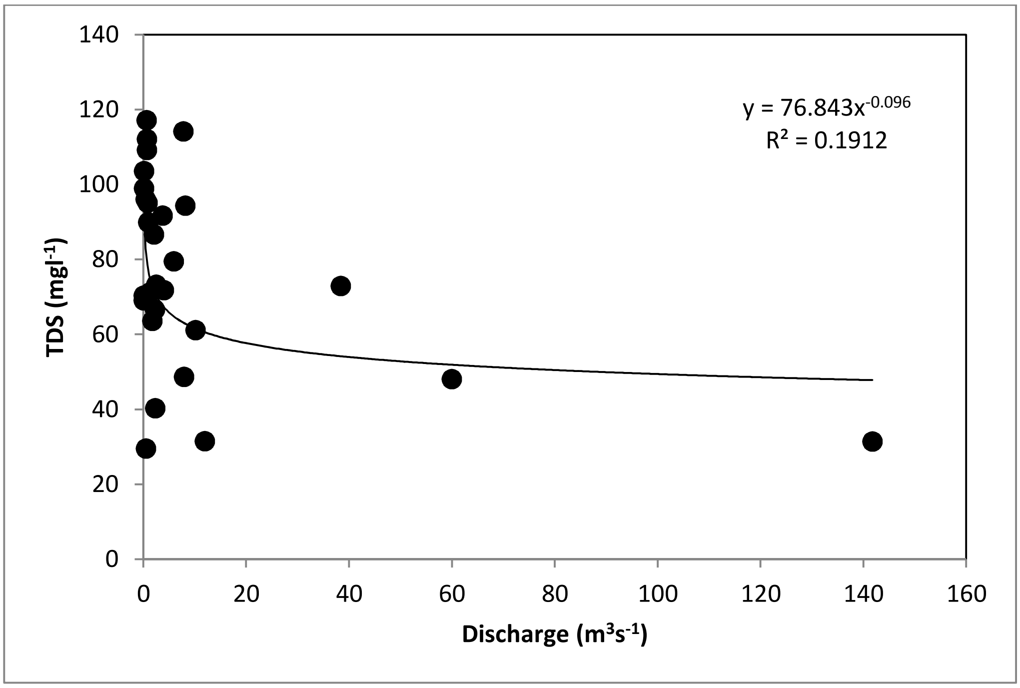

Figure 3b: Relationship between stream flow and TDS in Nzeeu river.

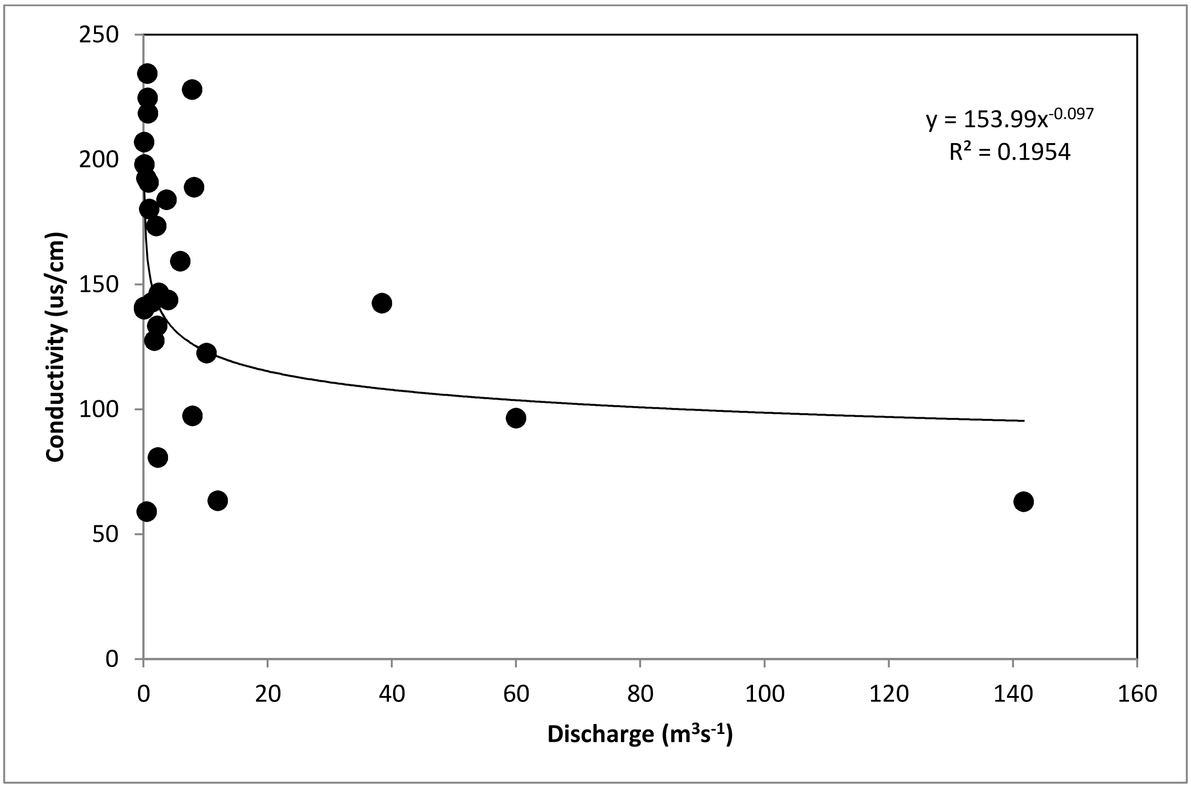

Figure 3c: Relationship between stream flow and conductivity in Nzeeu river.

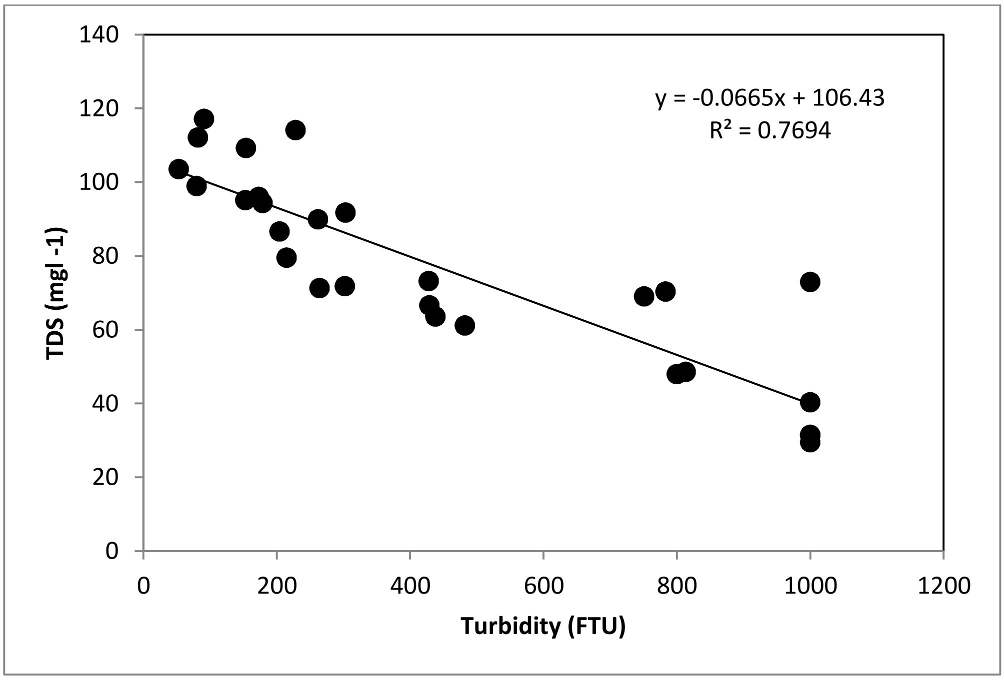

Figure 4: Relationship between TDS and turbidity in Nzeeu river.

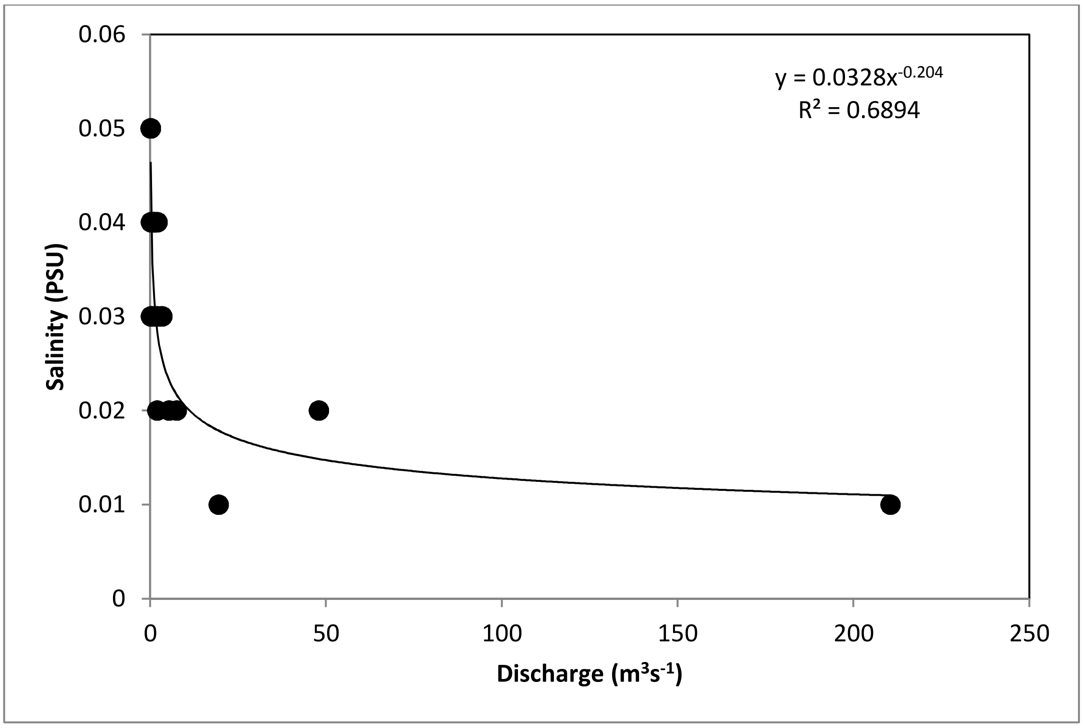

Figure 5a: Relationship between stream flow and salinity in Kalundu river.

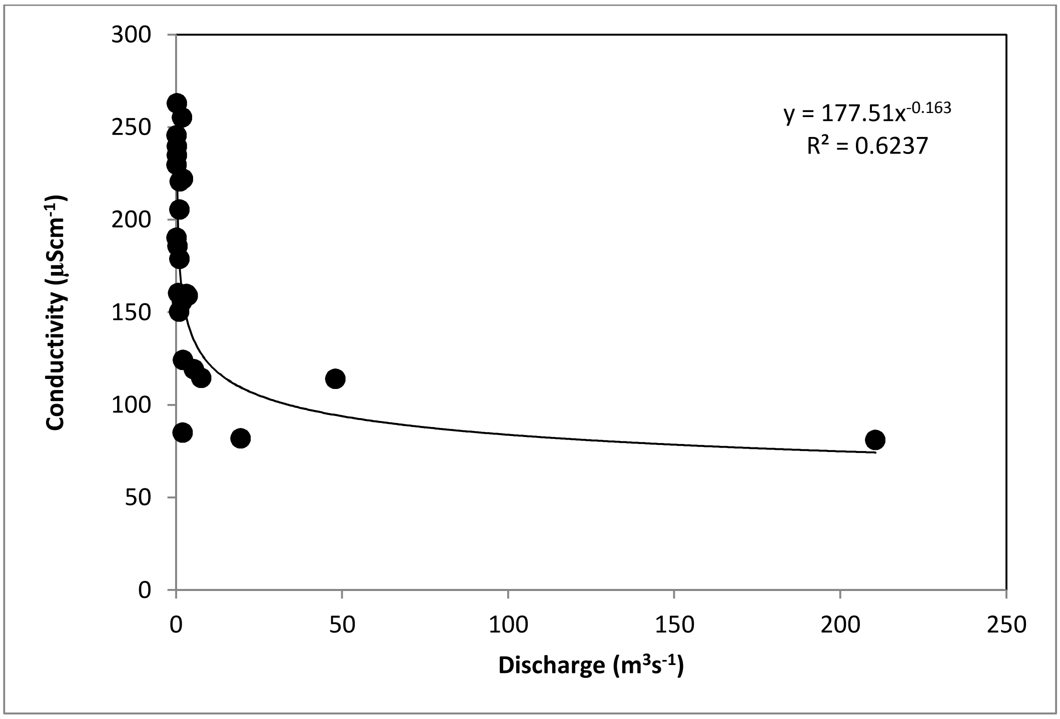

Figure 5b: Relationship between stream flow and conductivity in Kalundu river.

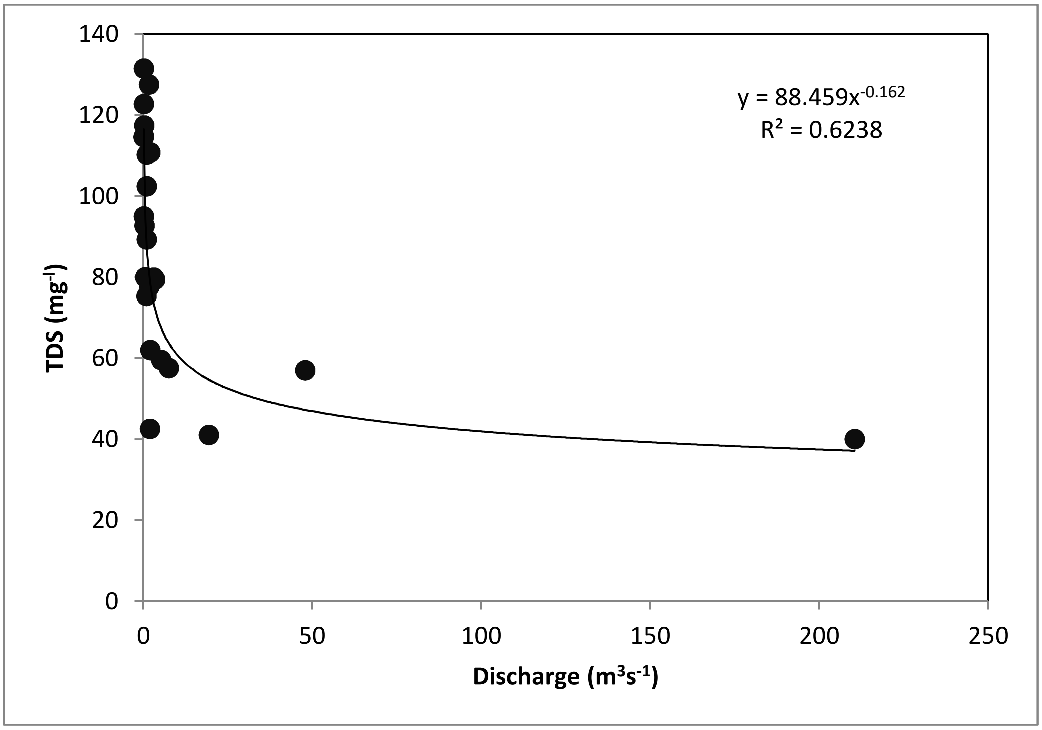

Figure 5c: Relationship between stream flow and TDS in Kalundu river.

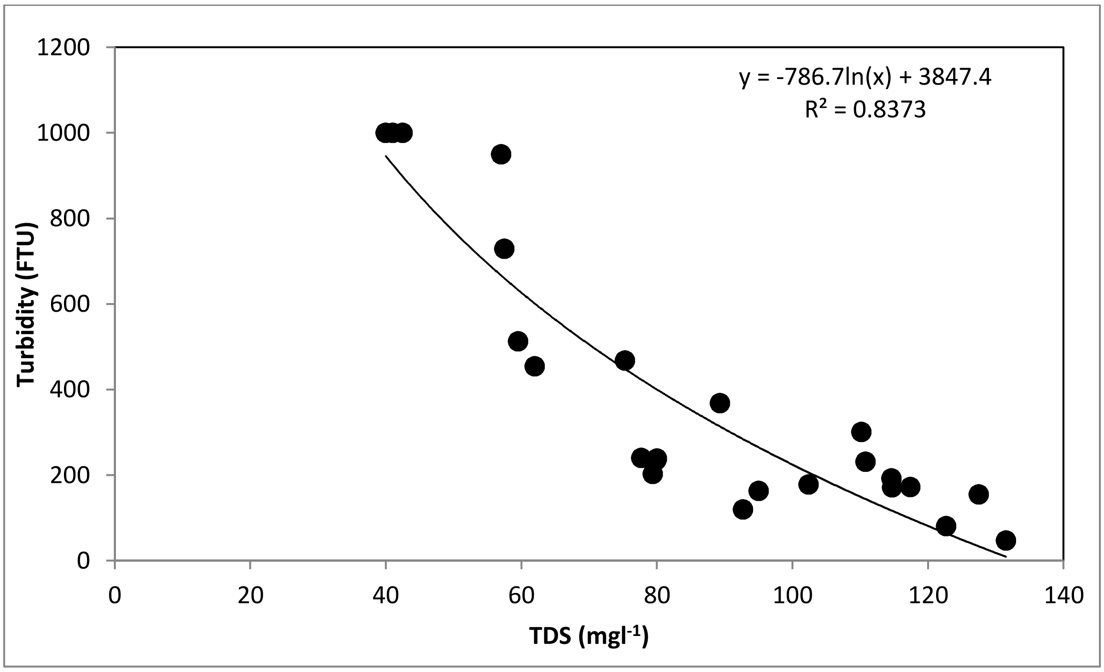

Figure 6 Relationship between TDS and Turbidity in Kalundu river.

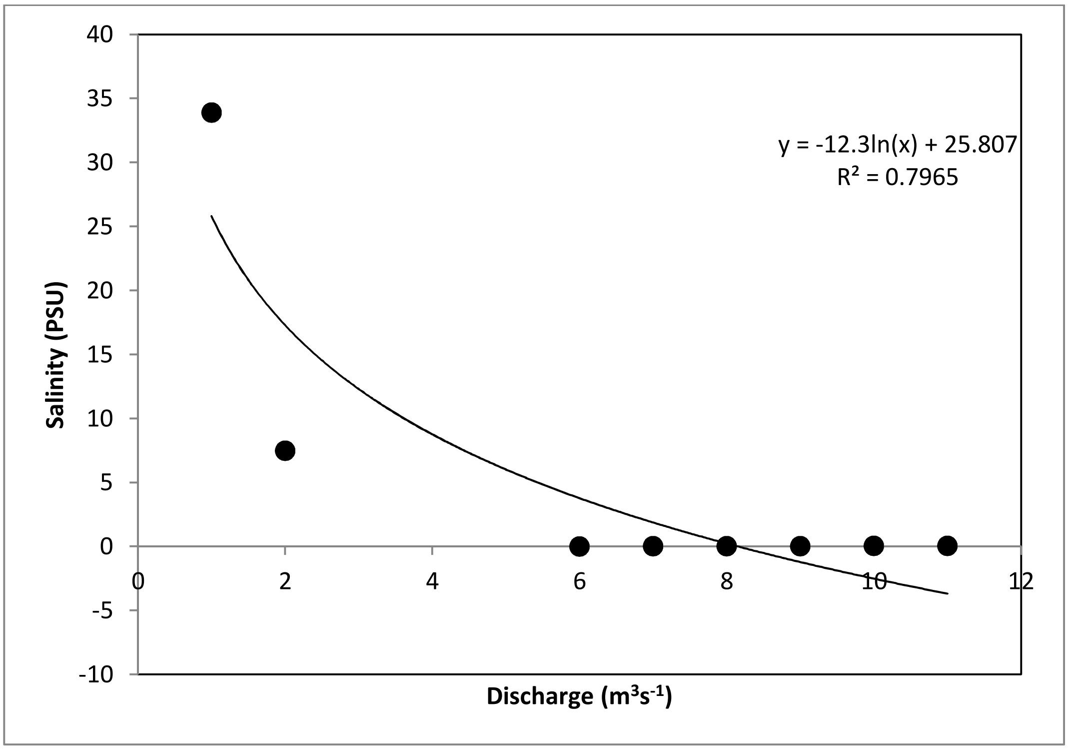

Figure 7a: Relationship between streamflow and salinity in Tiva river.

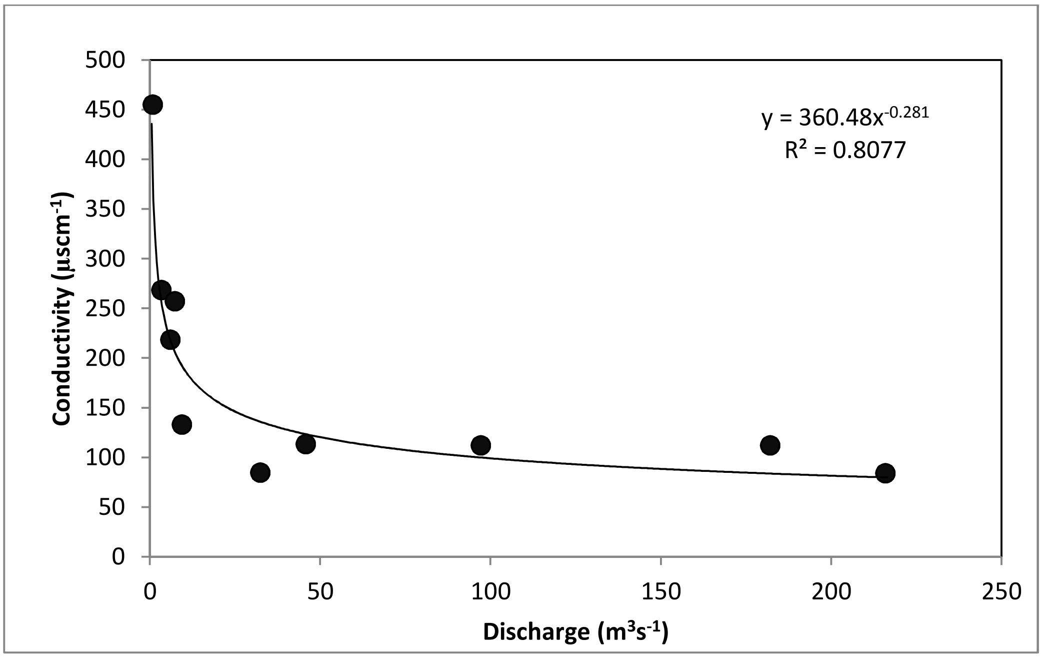

Figure 7b: Relationship between stream flow and conductivity in Tiva river.

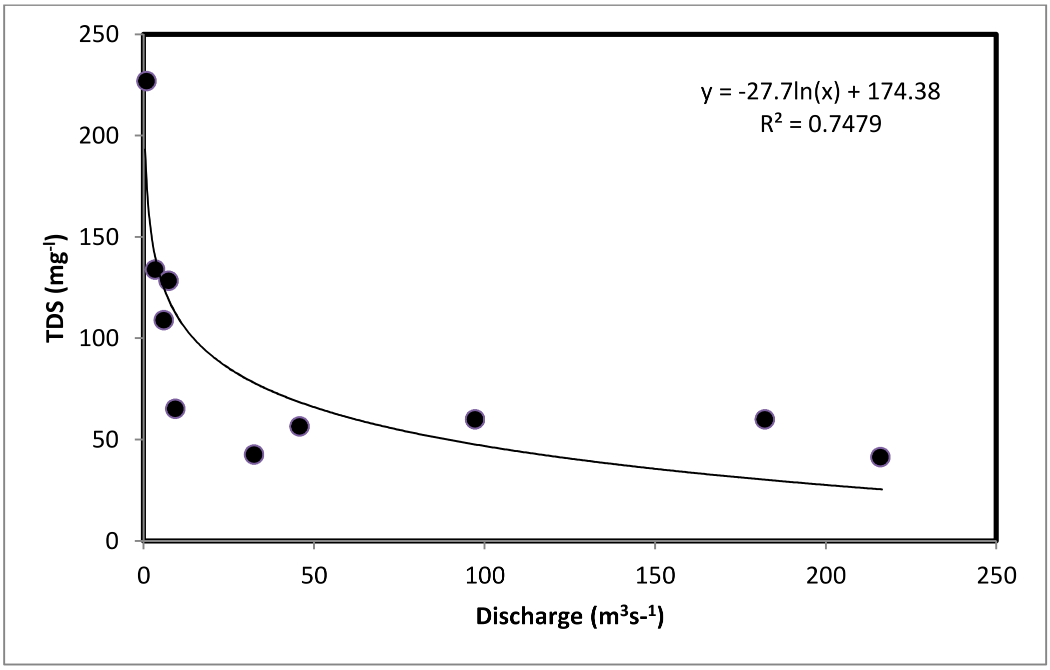

Figure 7c: Relationship between stream flow and TDS in Tiva river.

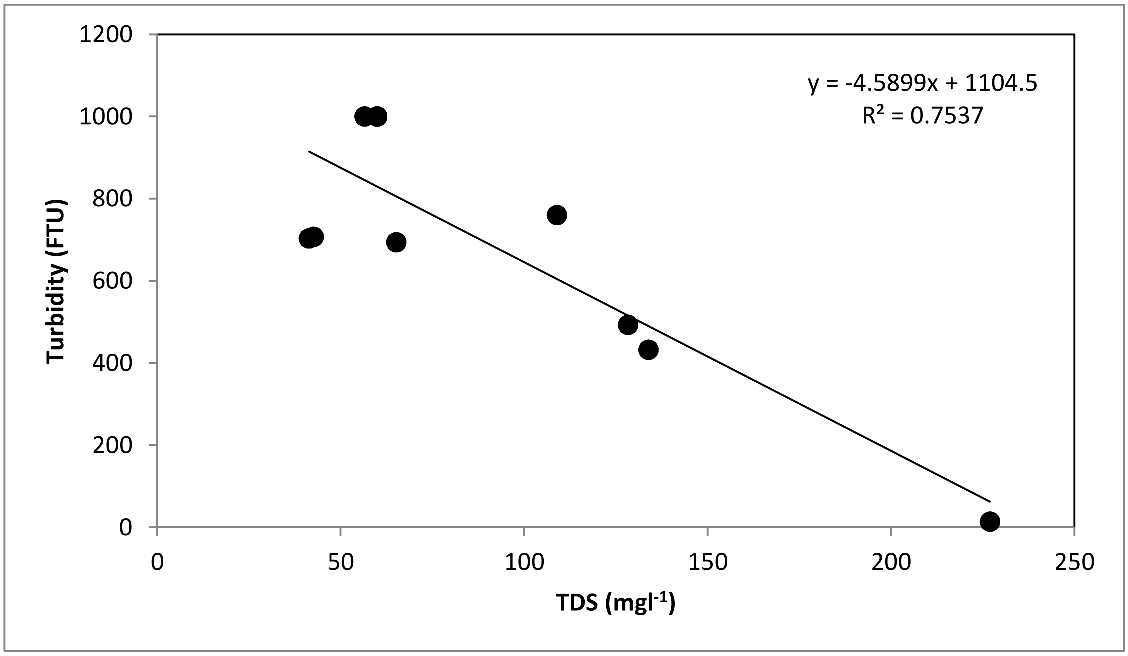

Figure 8: Relationship between TDS and Turbidity in Tiva river.

4.6 Relationship between streamflow and salinity-combined data for all sub-basins

Data for all tributaries draining into the Tiva river were combined and correlation and regression analyses conducted to establish the extent of the relationship between streamflow and physico-chemical parameters. The results of regression and correlation analyses showed weak relationships. For instance, the relationships between streamflow and conductivity yielded a R^2 value of 0.34 while that between streamflow and TDS yielded a R^2 value of 0.28. The relationship between streamflow and salinity yielded a R^2 value of 0.44. Although the relationships were best represented by power equations of the form $y = bX^{-e}$, the weak relationships indicate that these power function equations cannot accurately predict the related variables effectively. The weak relationships were attributed to the fact that each river subbasin presents unique combination of hydrologic, geologic, and landuse characteristics that contributes to the measured levels of salinity in their outlets.

4.7 Salt fluxes and discharge of salt downstream

The results showed significant fluxes of salt in the Tiva river. The salt is derived from the sub-basins that drains into the main river. Tables 4, 5, 6 and 7 shows the computed mean, maximum and minimum salt fluxes in the major rivers in the Upper Tiva Basin. Table 4 shows the total salt fluxes computed as a product of the mean streamflow rate (Q) and TDS concentrations and expressing the products in terms of salt flux per day and subsequently salt flux per year. The computations are based on an estimated period of 60 days when the river experienced streamflow that can be considered average. The assumption is that the seasonal rivers experience average streamflow rates for a period of 30 days in each of the short and long rainy seasons (see also Lasage et al., 2008).

Table 4: The computed values for salt flux in the Nzeeu and Kalundu Rivers

	TDS (mgl^{-1})		**River Discharge (m^3s^{-1})**		**Salt flux ($tons.day^{-1}$)**	
	Nzeeu	**Kalundu**	**Nzeeu**	**Kalundu**	**Nzeeu**	**Kalundu**
Mean	76.33	86.69	11.35	13.10	74.86	98.11
Max	117.1	131.5	141.75	210.6	1,434.15	2,392.75
Min	29.5	40	0.108	0.18	0.28	0.63
STD	25.84	28.46	28.61	43.27	63.87	106.38

Table 5: The computed values for salt flux in the Tiva River (Kabati) and Tiva (Kwa Vonza)

	TDS (mgl^{-1})		River Discharge (m^3s^{-1})		Salt Flux ($tons.day^{-1}$)	
	Tiva (Kabati)	Tiva (Vonza)	Tiva (Kabati)	Tiva (Vonza)	Tiva (Kabati)	Tiva (Vonza)
Mean	88.13	92.42	32.59	54.59	248.13	255.60
Max	223	227	136.5	216	2,629.97	944.39
Min	40.5	41.4	0	0	-	0
STD	61.58	58.31	56.09	77.35	298.45	332.08

Table 6: The computed values for salt flux in the Kauwi near Kabati and Mwitasyano

	TDS ($mg.l^{-1}$)		River Discharge (m^3s^{-1})		Salt Flux ($tons.day^{-1}$)	
	Kauwi	Mwitasyano	Kauwi	Mwitasyano	Kauwi	Mwitasyano
Mean	83.44	364.03	30.29	32.60	218.36	1,025.47
Max	200	894	168	118.13	2,903.04	9,124.16
Min	40	108.1	0.02	0.01	0.05	0.08
STD	55.36	358.07	59.901	57.18	286.51	1,768.95

Table 7: Total salt flux in the main Upper Tiva River at Tiva Market

	Sub-basin River	Sub-basin Area (Km^2)	Mean Annual Salt Flux ($tons.yr^{-1}$)	Mean Annual Salt Flux per unit area ($tons.m^{-2}.yr^{-1}$)	Contribution to the total salt flux (%)
1.	Nzeeu	1,200	4,491	3.74	4.48
2.	Kalundu	800	5,887	7.36	5.87
3.	Mwitasyano	1,000	61,528	61.53	61.32
4.	Tiva (Lower)	400	15,336	38.34	15.28
5.	Kauwi	200	13,102	65.51	13.06
	Total	**3600**	**100,344**	**27.87**	**100**

The results showed that the total salt flux in the upper Tiva basin is 100,344 $tons.y^{-1}$ (Table 7). The basin salt production rate varies from 3.74 to 61.53 $tons.m^{-2}.yr^{-1}$. Off all the sub-basins considered in this study, Mwitasyano had the highest salt flux that was attributed to the high salinity measured in the river. Thus, the majority of salt load emanates from Mwitasyano sub-basin that contributes 61% of the total salt flux in the Tiva Basin. The other sub-basins contributes about 40% of the total salt load. There is a possibility of additional salt input into the Tiva river as flows downstream since a number of other small tributaries joins the river south of Tiva Market.

Most of the salt load ends up in the lower Tana Basin in an area where the river forms a large inland delta (Ndarapo Swamp). The deposition of salt in the lower basin explains the whitish patches that are visible in the LANDSAT Satellite image (Figure 1). It is not certain whether all salts transported by Tiva river enters into Tana river through Laga Kokani or are retained within Ndarapo swamp. This is an area requiring further investigation since the river seems to lose substantial part of its volume once it leaves the swamp. Tiva basin salt flux is can be considered low when compared to the salt flux in the Colorado River System in United States where between 1940 and 1980, an average of approximately 9.4 million tons of salt per year were carried down the river every year. Since 1981, on average, approximately 8.8 million tons of salts have been measured in the Colorado river each year (U.S. Department of the Interior, 2011).

5. Discussion

5.1 Influence of streamflow on salinity

The variability of salinity, total dissolved solid and conductivity in the seasonal Tiva River Basin is influenced by processes associated with streamflow as well as flow of subterranean water into the river channel. The variability in salinity is related to streamflow and therefore there is a rapid change in salinity following a change in river discharge. There are also day to day variations in the levels of salinity such that the decrease of streamflow subsequently leads to an increase in salinity. There is usually a rapid increase in salinity during low flow conditions and this occurs within a period of < 1 month following cessation of rainfall in the basin. The rapid increase in TDS and salinity were attributed to the bank storage return flow and the subterranean groundwater flow to the river channel during low flow conditions. Water flowing into the river channel from groundwater aquifers and bank storage has high TDS concentration (cf. Kumaraswamy, 1991; Dembere 1998; Jain, 1998). The entrapment of water in deep metamorphic geological substratum leads to high residence time of subterranean groundwater. This allows more dissolution of rock minerals, thus increasing the level of TDS, salinity and conductivity. The mineralization of ground water due to entrapment and groundwater recharge of solubilised minerals from rocks and soils thus explains the high TDS and hence high conductivity. Higher mineralization imparts bad taste on potable water (Kumaraswamy, 1991; Dembere 1998; Jain, 1998).

The conductivity levels in Nzeeu river ranged 59 to 234 $\mu S.cm^{-1}$ with STD of ±51.4 $\mu S.cm^{-1}$ while that in Kalundu river ranged 81 to 262 $\mu S.cm^{-1}$ with STD of 57.4 $\mu S.cm^{-1}$. The conductivity in the lower Tiva (kwa Vonza) ranged 81 to 445 $\mu S.cm^{-1}$ with STD of 121.7 $\mu S.cm^{-1}$. The conductivity in Nzauwi river ranged 82 to 400 $\mu S.cm^{-1}$ with STD of 112.4 $\mu S.cm^{-1}$. The level of conductivity in Mwitasyano river ranged 217.7 to 1786 $\mu S.cm^{-1}$ with STD of 714.9 $\mu S.cm^{-1}$. The conductivity levels were generally much higher than ranges of 83 to 204 with STD of 45$\mu S.cm^{-1}$ reported by Waziri and Ogugbuaja (2012) in Yobe river in Nigeria. A study in polluted Thome river in Nairobi reported conductivity ranging 160-496 $\mu S.cm^{-1}$ (Karanja et al., 2015) which is higher than that recorded in all Tiva sub-basins, with the exception of Mwitasyano sub-basin where relatively much higher values were measured. In most cases, the maximum conductivity and TDS were higher than the maximum permissible drinking water conductivity of 150 $\mu S.cm^{-1}$ and 500 mgl^{-1}, respectively (WHO, 1993). The mean conductivity in Mwitasyano of 727.7$\mu S.cm^{-1}$ (Salinity = 1.1%; TDS = 364 mgl^{-1}) was generally much higher as compared to other sub-basins of the Tiva river. As will be discussed in the later sections, landuse seems to be playing an important in determining salinity levels in the Mwitasyano sub-basin.

The highest TDS, conductivity and salinity value were measured during the low flow conditions and lowest during high flow conditions. The low salinity levels during turbid high streamflow conditions can be attributed to increased ionic compounds in the water. This results in decrease in TDS, salinity and conductivity with an increase in turbidity as has been reported elsewhere by Waziri and Ogugbuaja (2012). The highest values measured during the low flow conditions were also attributed to the high evaporation rates that ranges between 1500 and 1600 $mm.yr^{-1}$ (Lasage et al., 2008). However, in the case of Mwitasyano river, the effects of high evaporation rates on salinity are aggravated by intensive cultivation/irrigation activities upstream. In this area, land approximating 30km^2 has been placed under intensive cultivation including irrigation using water from the Yatta canal. The irrigation return flows are usually channeled into Mwitasyano river. Irrigation increases the salt concentration of the source water by consuming water (evapotranspiration) and by dissolving salts in the underlying soil and geologic formations (U.S. Department of the Interior, 2011). In the case of other sub-basins of Tiva river, irrigation activities did not seem to an important factor in the variability of TDS, conductivity and salinity.

The relatively higher salinity levels in Mwitasyano river as compared to other sub-basins could also be explained by the nature of the drainage basin. The sub-basins such as Nzeeu and Kalundu have steep gradients and are composed of 1st and 2nd order streams with relatively short slope lengths and hence experiences rapid flow response to rainfall. In such streams, surface runoff generated by rainfall storms reaches the main river channel quickly and hence there is little time to dissolve soil/rock minerals. This explains the low salt production rates in the Nzeeu and Kalundu sub-basin (3.74 and 7.36 $tons.m^{-2}.yr^{-1}$, respectively). However, in the sub-basins such as Mwitasyano which is 3rd order stream receiving flow contributions from 1st and 2nd order streams with relatively gentle slope and longer slope lengths, the surface runoff generated by rainfall storms is able to infiltrate and percolate into the soil slowly enabling greater dissolution of soil/rock minerals. The subterranean water loaded with dissolved salts subsequently flows into the main river channel during periods when streamflow is subsiding. The maximum flow of the subterranean water into the river is attained when the hydraulic gradient is favourable during periods when streamflow has subsided.

During periods of low streamflow (and hence baseflow), there is a tendency for TDS concentrations to exceed the maximum permissible limit in drinking water of 1,000 $mg.l^{-1}$ (WHO, 1993). This imparts unpalatable taste to water and makes water unsuitable for irrigation due to heavy mineralization. However, the maximum TDS concentrations in the river are still lower than 2,000 $mg.l^{-1}$ above which production of laxative effect as a result of the presence of magnesium and sodium sulphate is expected (Kumaraswamy, 1991, Dembere 1998). The use of water for irrigation crop production is problematic since the TDS levels in the Mwitasyano river exceeds the maximum permissible limit of 500 $mg.l^{-1}$. It is thus expected that high TDS concentrations and hence high salinity levels in Mwitasyano river would affect irrigation crop production in dry season when irrigation of crops is most critical.

Measurements undertaken during periods of high streamflow of 270m^3s^{-1} yielded TDS concentrations of 200 mgl^{-1} in the main Tiva river branch. During periods of low streamflow of 0.4m^3s^{-1}, TDS concentration increased to 263 mgl^{-1}. Thus the TDS concentrations in the main branch of the river seem to be within the maximum permissible limit for drinking water and irrigation.

5.2 Non-linear relationships between streamflow and salinity

This study established non-linear relationships between streamflow and salinity, conductivity and TDS in all the seasonal rivers draining into the Tiva river that were subject of this study. Most of the relationships were best described using a regression power function as opposed to linear regression function (cf. Williams, 1966). The non-linear relationship established in this study can be attributed to the variable nature of the conductive mobility of the ionic species in the water. The high turbidity of Tiva river and its sub-basin streams during high flow conditions is due to the high suspended sediment load (>80%). The suspended sediment load is usually composed of non-conducting clays, silt and sand materials. The relatively high levels of these materials, in addition to dilution, leads to relatively lower conductivity of water during periods of high streamflow (cf. Waziri and Ogugbuaja, 2012). Past studies conducted elsewhere have shown that complex particulate matter consisting of both inorganic and organic chemicals, as well as microbial entities affects TDS and conductivity (Kaufman et al, 2005; Centeno, et al., 2006;Waziri and Ogugbuaja, 2010). There are also seasonal signals in the variability (Koning and Ross, 1999) that are related to the seasonal variations of rainfall and subsequently streamflows.

5.3 Salt fluxes into the lower basin

The results of computation river salt loads showed that Tiva river transports a significant volume of salt into its lower basin (Tables 4 -7). The river on average basis discharges 100,344 tonnes of salt per year. The average total salt production per unit basin area was computed as 27.87 tons.m^{-2}.yr^{-1}. Measurements undertaken during periods of high streamflow of $270m^3s^{-1}$ yielded a TDS concentration of 200 mgl^{-1} in the main Tiva river branch. Using this data, the maximum salt flux at the main Tiva branch is estimated to be 4,665 tons.day^{-1} which translates to 279,900 tons.yr^{-1}. Thus, it can be stated that salt flux in the upper region of the Tiva river ranges between 100,000 and 280,000 tons.yr^{-1}. The results show that most of the salt emanates from Mwitasyano sub-basin where salt production rate per unit area was 61.53 tons.m^{-2}.yr^{-1}. Salt production in river basins is mainly through weathering of metamorphic rocks. The discharge and deposition of salt into lower basin perhaps explains the whitish patches that are visible in satellite image as the river forms a large inland delta before it reconstitutes and flows to the Tana river as Laga Kokani in the area north of Garsen Town. It is unlikely that all salts transported by Tiva river enters into Tana river due to the possibility of high deposition in the inland delta/swamp with complex drainage network (Figure 1). This is however an area requiring further research investigations. It is however important to note that salt flux of between 100,000 and 270,000 tons per year is much lower than that for Colorado River System in United States where an average of approximately 8.8 million tons of salts have been measured in the river each year (U.S. Department of the Interior, 2011). The relatively low salt fluxes can be attributed to relatively lower stream discharge rates and lack of extensive irrigation activities in the basin with the exception of Mwitasyano sub-basin where irrigation is practiced to a certain extent.

5.4 Implications on water resources and agricultural development

This study has demonstrated the dynamics of salinity production and transport in the upper Tiva river basin, as determined by the measurements of salinity, TDS concentrations and conductivity. While, the salinity, TDS concentrations and conductivity levels in the river are below the maximum permissible levels for drinking water and irrigation, there is a possibility of salinity increasing in future. This is expected in view of expansion of small-scale irrigation activities in the basin, including also over-abstraction of groundwater aquifers. High levels of salinity will make water unpalatable and reduce the extent to which river water can be used for domestic purposes. Also, increased salinity will complicate irrigation activities in the basin by increasing sodicity of soil that would eventually reduce agricultural crop yields. High levels of salinity can also cause corrosion and plugging of water supply pipes and fixtures in housing and industry as has been reported in the Colorado river basin in the US (U.S. Department of the Interior, 2011). This will make rural water supply projects expensive and unsustainable due to high operation and maintenance costs.

While natural causes of salinity are difficult to control, anthropogenic factors that can lead to escalation of the salinity problem in the basin can be managed through targeted interventions (see U.S. Department of the Interior Report, 2011). There is a need for water resources and agricultural development programmes in the semi arid Tiva River Basin to promote sustainable irrigation practices and control land degradation, particularly extensive clearance of vegetation to open land for agriculture and settlement. Retention of sufficient vegetation cover would increase infiltration and percolation of water during rainy season and therefore dilute saline groundwater that eventually flows into the rivers. Construction of large water storage dams in the Tiva river is recommended. This will hydrologically modify the flow of the river downstream, and hence significantly reduce and alter the salinity variability in the downstream areas. On long term basis, salinity effects of the reservoirs are beneficial and will greatly reduce the levels of salinity in the river (see also U.S. Department of the Interior, 2011).

6. Conclusions

This study focused on establishing the extent to which salinity in the seasonal Tiva river basin is influenced by streamflow. The study has established that salinity in the basin is subject of complex interrelationships between river hydrology, geology and to a certain extent landuse. The salinity levels are generally low with the exception of Mwitasyano tributary that receives irrigation return flow. There is a significant seasonal variation of salinity including the related parameters-TDS concentrations and conductivity. Low levels of salinity, TDS and conductivity were experienced during periods of high streamflow when the water was highly turbid. The low conductivity experienced during this period was attributed to the dilution effect of high streamflow and also due to the presence of high quantity of non-conductance inorganic materials such as sand and clay. The low streamflows were characterized by high levels of TDS and hence salinity and conductivity. This was attributed to the accumulation of dissolved solids associated with the bank storage return flow and seepage of subterranean groundwater into the river channel. High evaporation rates and lack of sufficient flow to flush out dissolved solids further intensifies the accumulation of salts during dry season. The salinity increases rapidly after cessation of streamflow in rainy season. The study showed that Tiva river transports between 100,000 and 270,000 tonnes of salt to the lower basin every year. While most of the salinity can be attributed to the nature of metamorphic rocks, irrigation seems to be contributing to high dry season salinity associated with low flow in Mwitasyano sub-basin. The study calls for water resources and agricultural development programmes in the basin to promote sustainable irrigation practices and control land degradation, particularly extensive clearance of vegetation to open land for agriculture and settlement. The construction of water storage reservoirs can help in controlling increases in salinity in the Tiva river.

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